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Modeling the response of tropical highland herbaceous grassland species to climate change: The case of the Arsi Mountains of Ethiopia



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ABSTRACT

Global warming is forcing plant and animal species to respond either through pole-ward or upslope migration to adjust to temperature increases, and grassland communities are not an exception to this phenomenon. In this study, we modeled the response of herbaceous species of grasslands within the Arsi Mountains in Ethiopia under no-migration and with migration scenarios to the projected 4.2 °C increase of temperature by 2090 (under the A2 emission scenario). For 67 species of grasses and legumes, we determined the current and predicted altitudinal limits and calculated current and projected area coverage using a Digital Elevation Model. The results indicated that the projected warming significantly reduced altitudinal ranges and habitat areas of all the species studied. All the studied species faced range contraction and habitat loss with range shift gaps among forty two species under the no-migration scenario. With the migration scenario, however, the forty two species with range shift gaps are predicted to benefit from at least some habitat area retention. Between growth forms, legumes are predicted to lose significantly more habitat area than grasses under the no-migration scenario while no significant difference in habitat area loss is predicted under the migration scenario. It can be concluded that management options are required to facilitate upslope species migration to survive under the warming climate. This could involve leaving suitable dispersal corridors and assisted colonization depending on species behavior and level of extinction risk predicted under the projected warming.

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1. Introduction

Grasslands constitute a significant portion of the tropical environment, and the area under grasslands is contracting over time due to crop land expansion, increased intensity of grazing, and an overall environmental degradation. Grasslands are highly responsive to temperature, precipitation and grazing pressures (Adler and Levine, 2007; Anderson, 2006; Vicca et al., 2007; White et al., 2012). The distribution of grasslands is determined by many environmental factors among which climate, mainly through temperature, determines floristic distributions along altitudinal gradients (Pausas and Austin, 2001; Colwell and Rangel, 2010). Among the dominant and important floristic constituents of grasslands, grass species have a wider range of adaptation to the different climatic

gradients than any other family of flowering plants, while legumes have a relatively narrow range of adaptation (Gebbru, 2009).

However, the current global warming in conjunction with increased grazing pressure and land use for other purposes places pressure on the distribution and floristic composition of grasslands (Klein et al., 2007). Under warming scenarios, climate change will induce upward species movements as long as the elevation of the landscape will allow this to happen (Colwell et al., 2008; Kreyling et al., 2010; Laurance et al., 2011; McCain and Colwell, 2011; Sheldon et al., 2011). However, the net movement of species upslope could lead to disappearance and decline of species in the lowlands, and at lower elevations, and also lack of a source pool of species adapting to higher temperatures to fill gaps causing 'lowland biotic attrition' (Colwell et al., 2008; Feeley and Silman, 2010). On the other hand, there could be extinction of mountain top species where there are no more escape routes available to move into (Colwell et al., 2008; Jansson, 2009; Kreyling et al., 2010).

The response to the observed and predicted climate change, however, is species and mountain range specific (Pauli et al., 1996; Klanderud, 2008). Some species are unable to shift into a

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newly suitable geographic range due to dispersal barriers and/or insufficient dispersal capabilities related to species differences, altered species interactions, phenology, resource availability, loss of dispersal vectors and other factors causing extinction risks without species range shift (Feeley and Silman, 2010; Larsen et al., 2011; Friggens et al., 2012; Urban et al., 2012). Many mountain plant species are slow growers with narrow habitat bounds. They tend to be intolerant to competition from the incoming fast-growing lowland species which are therefore more likely to expand into new regions because of their wider range of adaptation (Cochrane, 2011; Angert et al., 2011; Hoiss et al., 2013). As a result, range differences between present and future ranges – ‘range shift-gaps’ develop earlier for narrow-ranged species (Colwell et al., 2008). Furthermore, human-induced disturbances through land fragmentation and heavy grazing pressure in many tropical mountain areas, including in Ethiopia, have left very narrow strips of road side, farm boundaries, river banks, very steep slopes and very isolated patchy area closures or refugia as dispersal corridors available for species redistribution. The opportunities for a species to move freely elsewhere are limited. Thus because of climate-driven habitat loss, increased physiological stress, extreme climatic events, changes in fecundity and other factors (Pauli et al., 1996; Feeley and Silman, 2010; Larsen et al., 2011), the chance for extinction or population decline at a given site is high (Colwell et al., 2008).

Thus a priori knowledge of which species are likely to exhibit range shift-gaps, range contractions, habitat area loss, habitat area gain or extinction risk under global warming would be of great benefit to resource managers and others (Angert et al., 2011). An effective response to these threats requires reliable information on which species are likely to be threatened (Akçakaya et al., 2006) under two scenarios. The first scenario is where the species will not have the chance to shift its current upper range limit due to lack of dispersal corridors or suitable habitat to move into while there will be climate forced shift in its lower altitudinal range limit. The second scenario is where each species is not subjected to anthropogenic barriers and has suitable dispersal corridors to shift both its upper and lower altitudinal limits. Hence, this paper presents predicted responses of economically and environmentally important herbaceous grassland species of the Ethiopian highlands to the two scenarios, taking the case of the Arsi Mountains. We use the model developed by Colwell et al. (2008) which has also been used for similar studies by Kreyling et al. (2010) and Feeley and Silman (2010).

2. Materials and methods

2.1. Description of the study area

The study area is located in the Arsi Zone of the Oromiya National Regional State, Ethiopia and extends from 7°27'46.048"N to 8°24'54.605"N latitude and 38°59'32.009"E to 39°37'55.082"E longitude within the central highlands of Ethiopia. The landscape is generally sloped with increasing altitude from the lowest point in the Central Rift Valley (less than 1500 m) to the highest point at Chilalo Mountain (4036 m) (Fig. 1).

Modified by altitude, the climate of the study area varies from warm tropical conditions in the Rift Valley to cool Afro-alpine highland conditions in the mountains. The area has three annual seasons: the dry season – October to January, the small rainy season – February to May and the main rainy season – June to September. The mean annual rainfall varies from 663 mm (1967–2008) at Koka (1595 masl) in the Rift Valley to 817 mm (1967–2008) at Kulumsa (2200 masl) and 1149 mm (1967–2008) at Asela (2350 masl). The mean daily maximum to minimum temperature range also varies from 29.8 to 14.9 °C (1967–2008) at Koka to 23.1–10.0 °C (1967–2008) at Kulumsa and 21.5–9.0 °C (1967–2008) at Asela.

The vegetation of the study area varies from the Acacia-wooded grassland in the Central Rift Valley to the degraded Afro-alpine montane forests and associated grassland in the highlands (White, 1983; Friis, 1992). The lowlands in the Rift Valley were once dominated by Acacia woodland but much of the land is now under cultivation with beans, maize, sorghum, teff and wheat. The mid altitudes to highland areas are dominated by plantations of exotic *Eucalyptus* species. The native montane tree species such as *Cordia africana*, *Juniperus procera*, *Hagenia abyssinica*, *Olea africana* and *Podocarpus fulcatus* have steadily disappeared with small remnants scattered in agricultural fields and small uncultivated areas. A large area of land is under extensive cultivation of barley, faba bean, field pea, flax, rapeseed and wheat. The upper Afro-alpine region, above 3000 masl is home for the endemic Mountain Nyala (*Tragelaphus buxtoni*) and is dominated by *Hagenia*–*Juniperus* vegetation types. The upper most extremes are covered by species of *Artemisia*, *Erica* and *Hypericum* (Friis, 1992; Evangelista et al., 2007). At present much of the Afro-montane forest has been cleared and replaced by cultivation of cereal crops. It is common to see barley cultivated at above 3400 masl extended beyond the 3200 m limit reported in 1989 (Evangelista et al., 2007). Such progressive encroachment of cultivation although primarily due to increasing human demographic pressure, might also be a sign of rising temperatures opening up higher areas for cultivation.

2.2. Sampling

A total of 60 observational plots, each 50 m by 50 m, were surveyed at the end of the main rainy season when the majority of grasses and legumes come into flower. Sampling thus took place between August in the Rift Valley and October 2010 in the mountains. Sampling was done along an altitudinal gradient from Rift Valley starting at 1342 m southward up to 3410 m altitude on the Chilalo Mountain. Beyond this limit we were not able to sample on moorlands because of heavy grazing pressure by domestic animals during the main rainy season and intensive Giant mole rat foraging and damage leading to an absence of vegetation cover to sample.

The major part of the land in the study area is kept under extensive cultivation and hence sampling was conducted on random plots scattered along an altitudinal gradient on lands not cultivated for a minimum of five years. Sampling sites included un-grazed sanctuaries, farm land boundaries, hill sides, road sides, river and stream sides, enclosures, school yards, church yards and other institutional compounds and grazing lands. For each sampling plot a quadrat of 1 m² was thrown and the central point was used as a reference point. Specimens of grasses and legumes located within 25 m radii to the north, south, east and west of the reference point were collected and identified at the International Livestock Research Institute (ILRI) Addis Ababa Herbarium facility and the National Herbarium of Addis Ababa University. Identification and nomenclature of voucher specimens followed Hedberg and Edwards (1989) and Phillips (1995). For each plant species we recorded geo-references and altitudes with GPS.

2.3. Estimation of current and future altitudinal range of plant species

The altitudinal range was assigned to be zero for species recorded only at one sampling plot and these were excluded from the analysis. All the noted ranges were interpolated by assuming continuous ranges from lowest to the highest occurrence in the data set. The current range of occurrence for each species was determined as 2.5% and 97.5% quintiles of the actual observed lower and upper altitudinal limit, respectively for each species as indicated by Feeley and Silman (2010) rather than range estimate downslope or upslope half-way to the nearest plot and

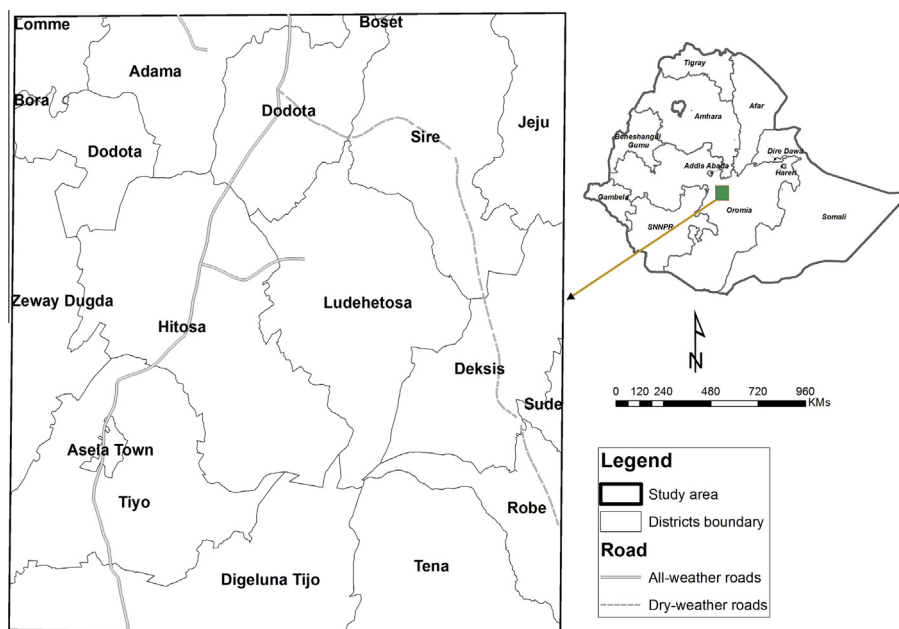


Fig. 1. Map showing location of the study area in Ethiopia.

extrapolating halfway to the altitude of the lowest and the highest points (Colwell et al., 2008 and Kreyling et al., 2010). This was to minimize the influence of outliers that can arise from geo-referencing errors particularly at the lowest and the highest points.

The future range limits for 2090 were projected under two scenarios. The first scenario is termed the no-migration scenario where the species will not have the chance to shift its current upper limit due to lack of suitable dispersal corridors or suitable habitat to move upslope while there will be a shift in its lower altitudinal limit. The second scenario, termed the migration scenario is where each species has no anthropogenic barriers and has suitable dispersal corridors left to shift both its upper and lower altitudinal limits. The range limits for these two scenarios were estimated by adding 700 m to both the current upper and lower range limits in case of the second scenario and by adding 700 m only to the current lower limits while the current upper limit remain unchanged for the no-migration scenario. The 700 m estimate of altitudinal shift is a predicted response of species to 4.2 °C increase of temperature estimated for Ethiopia for 2090 (McSweeney et al., 2010) under the A2 emissions scenario with the adiabatic lapse rate of 0.6 °C/100 m (Kreyling et al., 2010). Species range shift gaps, area, attrition, range contraction and extinction risks were estimated as follows under both scenarios:

A range shift gap is expected to occur when there is a physical gap between the upper limit of a species' current altitudinal distribution and the lower limit of its predicted altitudinal distribution under a future climate scenario (Colwell et al., 2008). Lowland biotic attrition is expected to occur as local species disappear from lower elevations due to upslope range movement (Colwell et al., 2008). Range and/or habitat contraction is expected to occur when there is habitat and /or range loss (Colwell et al., 2008).

2.4. Estimation of change in habitat area

It is evident that mountains, because of their natural cone shape, have a wider area at their bottom which declines with increase in altitude, and the available habitat for species is negatively correlated with altitude. The current and future predicted area of each species along altitudinal gradient (bound between the lower and upper altitudinal limits) were determined by using a Digital

Elevation Model (DEM) and the percentage change in habitat area, as a measure of relative risk of extinction, was determined by the following index as explained in Feeley and Silman (2010) under both scenarios:

$$\text{Change in area} = 100 \times (A_F - A_C) / A_C$$

where A_C is the current area; A_F is the future area.

The implication is that species that lose a greater percentage of habitat area are under greater risk of extinction (Feeley and Silman, 2010).

2.5. Data analysis

Data on current and projected lower and upper altitudinal limits, range of altitude, habitat area, and projected area change (scenarios 1 and 2) were described for each species. Relationship between species richness and altitude, altitudinal range of species and altitude, area coverage of species and altitude, and area coverage and altitudinal range of species were explored using x–y graphs using altitude as a predictor and number of species, altitudinal range and area of species as response variables.

The species were sorted into possible genera, growth forms, life forms and mode of propagations according to descriptions given by Hedberg and Edwards (1989) and Phillips (1995). Comparisons were made among genera, growth and life forms and mode of propagation for current and projected scenarios' altitudinal range and area using the general linear model (GLM) procedure of SAS Institute (2002) which assumes normal distribution of the error term. Significant differences among genera, growth forms, life forms and mode of propagations were separated by employing the Duncan Multiple Range Test at the five percent level of significance.

3. Results

3.1. Current species distribution

A total of 53 grass and 14 legume species belonging to 30 grass and six legume genera were collected from the field. Eight grasses and three legume genera were represented by two or more species and accounted for 62.7% of the data set.

From the results of the regression analysis it is apparent that, the number of species sampled showed a clear tendency of higher concentration at intermediate altitudes (Fig. 2a) where most species have a wider altitudinal range (Fig. 2b). The current area available for each species showed a decreasing tendency with altitude (Fig. 2c) but increased with available altitudinal range for some species (Fig. 2d).

Among the 67 studied species, *Cynodon dacylon*, *Eleusine floccifolia*, *Medicago polymorpha*, *Pennisetum schimperi*, *Pennisetum trisetum*, *Sporobolus natalensis*, *Sporobolus consimilis* and *Trifolium burchellianum* are some of the species with wide altitudinal ranges. On the other hand, *Eragrostis welwitschii*, *Harpachne schimperi*, *Hyparrhenia rufa*, *Indigofera spicata* and *Panicum maximum* are some of the species with narrow altitudinal ranges (Appendix Table).

With regard to current habitat area, *Cenchrus ciliaris*, *C. dacylon*, *Eragrostis tenuifolia*, *P. schimperi*, *S. consimilis* and *S. natalensis* are among the species with extensive habitat area. On the contrary, *Eragrostis botryodes*, *E. welwitschii*, *Eulalia polyneura*, *H. rufa*, *H. schimperi*, *Lolium temulentum*, *Panicum calvum*, *Pennisetum clandestinum*, *Trifolium cryptopodium* are among the species covering relatively limited habitat area (Appendix Table).

Among the 11 genera, *Hyparrhenia*, *Indigofera*, *Panicum* and *Vicia* showed significantly ($P < 0.05$) narrower altitudinal range compared to the genus *Sporobolus* which showed the highest altitudinal range. Between the two growth forms (legume and grass), life forms (annual and perennial) and mode of propagations (clonal and non-clonal) no significant ($P > 0.05$) differences were noticed with respect to the current altitudinal range, while the grass growth form revealed significantly ($P < 0.05$) higher mean habitat area than the legume growth form (Table 1). With respect to current area available for the genus, the habitat area available for the genus *Trifolium* was significantly ($P < 0.05$) lower than that available for

Chloris. No significant ($P > 0.05$) differences were found among the other genera (Table 1). Between the two growth forms, the grass growth form showed significantly ($P < 0.05$) higher habitat area available than the legume growth form, whereas there was no significant ($P > 0.05$) difference between the annual and perennial life forms nor between the clonal and non-clonal modes of propagation.

3.2. Projected species distribution under future climate change (Scenario 1)

All species are predicted to face range contraction under Scenario 1 (Appendix Table). At the species level, forty two species, among which 10 legume species (71%) and 32 grass species (60%) are predicted to face physical gaps between the projected lower altitudinal limit and the current upper altitudinal limit of the species (Appendix Table). Among the 11 genera, a range shift gap is predicted to affect the genera *Chloris*, *Indigofera*, and *Vicia*. No significant differences were observed between the grass and legume growth forms or between the annual and perennial life forms or between the clonal and non-clonal modes of propagation (Table 1).

For all species, the predicted change in altitudinal range corresponds to changes in habitat area (Fig. 3). The 42 species with range shift gaps (representing 63% of the data set) are predicted to lose their entire current range and habitat area. Hence, these species are predicted to face certain local extinctions. The remaining 25 species are predicted to lose on average 91% of their current habitat area. Among the 11 genera complete habitat loss is predicted to occur among the genera *Chloris*, *Indigofera* and *Vicia* (Table 1). Ten of the fourteen legume species are predicted to face complete loss of habitat with expectations of extinction, while the remaining four species (*M. polymorpha*, *T. burchellianum*, *Trifolium simense* and *Trifolium semipilosum*) are predicted to lose about

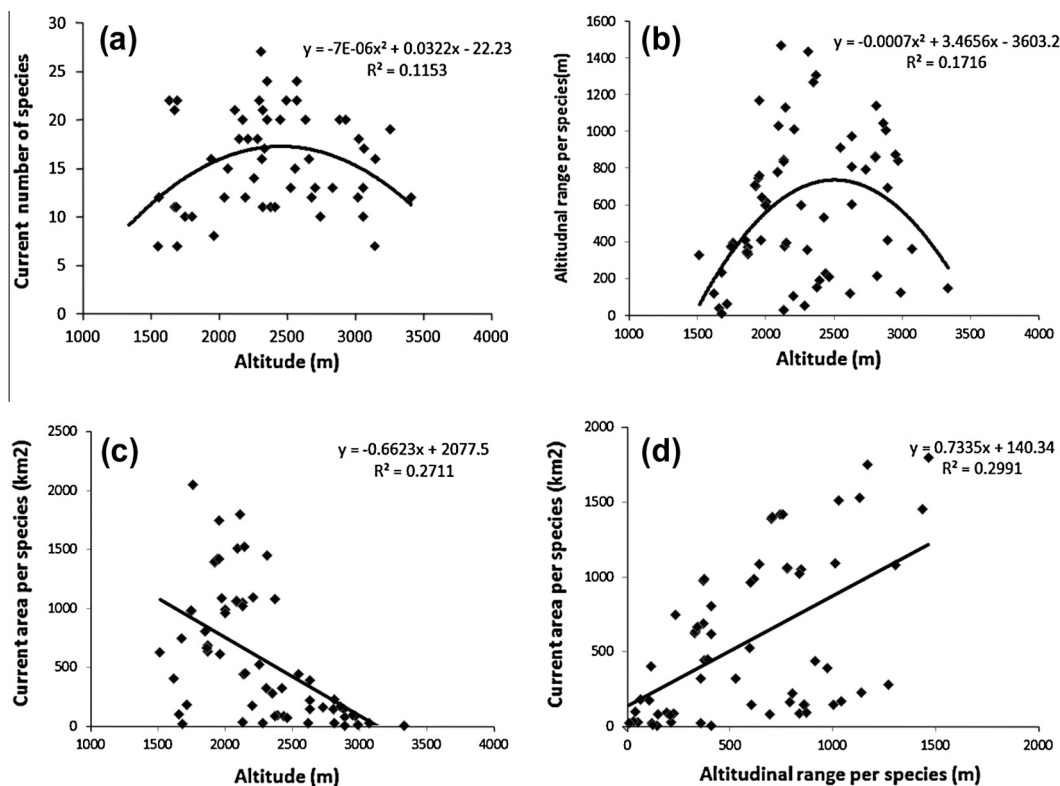


Fig. 2. Current number of species per altitudinal gradient (a), altitudinal range of species per altitudinal gradient (b), current area of each species per altitudinal gradient (c) and current area of each species per altitudinal range of species (d) determined based on GPS reading and Digital Elevation Model of the current altitudinal range for each species.

Table 1

Current condition and projected response of the common grass and legume genera of the study area to the projected 4.2 °C warming by 2090 under no-migration and with migration scenarios.

Description	No species	Current distribution		Scenario 1 (no-migration)			Scenario 2 (migration)		
		Altitudinal range (m)	Area (km ²)	Altitudinal range (m)	Area (km ²)	Area change (%)	Altitudinal range (m)	Area (km ²)	Area change (%)
<i>Genus</i>									
<i>Andropogon</i>	3	880.3 ^{ab}	253.0 ^{ab}	180.7 ^{ab}	14.33 ^b	−94.7 ^{ab}	880.3 ^{ab}	30.44 ^b	−87.4 ^a
<i>Chloris</i>	2	659.8 ^{ab}	1188.4 ^a	0.0 ^b	0.0 ^b	−100 ^b	659.8 ^{ab}	152.5 ^{ab}	−87.2 ^a
<i>Eleusine</i>	2	856.9 ^{ab}	943.6 ^{ab}	302.0 ^{ab}	52.0 ^b	−95 ^{ab}	856.9 ^{ab}	120.8 ^{ab}	−87.0 ^a
<i>Eragrostis</i>	5	429.1 ^{ab}	544.3 ^{ab}	81.2 ^{ab}	33.2 ^b	−97 ^{ab}	429.1 ^{ab}	70.1 ^b	−87.2 ^a
<i>Hyparrhenia</i>	3	406.5 ^b	678.5 ^{ab}	9.3 ^b	5.4 ^b	−99.7 ^b	406.5 ^b	88.9 ^{ab}	−87.3 ^a
<i>Panicum</i>	3	336.3 ^b	386.0 ^{ab}	48.7 ^{ab}	21.6 ^b	−98.7 ^b	336.3 ^b	49.1 ^b	−85.8 ^a
<i>Pennisetum</i>	6	792.0 ^{ab}	565.9 ^{ab}	248.2 ^{ab}	46.4 ^b	−95.0 ^{ab}	792.0 ^{ab}	72.3 ^b	−86.9 ^a
<i>Sporobolus</i>	3	1097.3 ^a	1135.4 ^{ab}	399.0 ^a	114.0 ^a	−88.7 ^a	1097.3 ^a	227.7 ^a	−82.2 ^a
<i>Indigofera</i>	3	231.3 ^b	450.4 ^{ab}	0.0 ^b	0.0 ^b	−100 ^a	231.3 ^b	60.3 ^b	−83.6 ^a
<i>Trifolium</i>	6	679.6 ^{ab}	149.9 ^b	101.3 ^{ab}	5.8 ^b	−95.0 ^{ab}	679.6 ^{ab}	18.9 ^b	−73.1 ^a
<i>Vicia</i>	2	248.4 ^b	313.0 ^{ab}	0.0 ^b	0.0 ^b	−100 ^b	248.4 ^b	29.6 ^b	−91.6 ^a
<i>Growth form</i>									
Grass	53	586.1 ^a	663 ^a	113.2 ^a	33.7 ^a	−89.4 ^a	586.1 ^a	98.3 ^a	−78.4 ^a
Legume	14	498.2 ^a	270.2 ^b	84.07 ^a	9.71 ^a	−96.9 ^b	498.2 ^a	40.3 ^b	−85.6 ^a
<i>Life form</i>									
Annual	20	522.1 ^a	484.5 ^a	123.2 ^a	35.8 ^a	−96.4 ^a	522.1 ^a	77.5 ^a	−84.4 ^a
Perennial	47	587.2 ^a	622.1 ^a	69.3 ^a	12.1 ^a	−97.0 ^a	587.2 ^a	89.9 ^a	−85.9 ^a
<i>Mode of propagation</i>									
Clonal	27	634.6 ^a	665.2 ^a	126.0 ^a	44.7 ^a	−96.1 ^a	635.0 ^a	99.7 ^a	−85.1 ^a
Non-clonal	40	522.6 ^a	524.2 ^a	94.3 ^a	17.9 ^a	−97.0 ^a	522.6 ^a	77.1 ^a	−85.9 ^a

Means with the same letters in a column are not significantly ($P > 0.05$) different from each other.

84% of their current habitat area (Appendix Table). Between the two growth forms, the legume growth form is predicted to show significantly ($P < 0.05$) higher loss of habitat than the grass growth form while no-significant ($P > 0.05$) differences were recorded neither between the annual and perennial life forms nor between the clonal and non-clonal modes of propagation (Table 1).

3.3. Projected species distribution under future climate change (Scenario 2)

Under Scenario 2 all species are predicted to maintain their current altitudinal range since they are allowed by the model to proportionally shift the current lower and upper altitudinal limits. Nevertheless, many species are predicted to lose a significant proportion of their current habitat area mainly due to less area available on the upper portion of the mountains to which they migrate upslope. The species are predicted to lose an average of about 84% of their current habitat area (Fig. 3) with over 90% loss to occur among *C. ciliaris*, *Exothea abyssinica*, *P. calvum* and *Trifolium ruppellianum*. The lowest losses are predicted to occur among *T. cryptopodium* (2.6%), *Echinochloa colona* (44.8%) and *M. polymorpha* (55%) (Appendix Table). The forty two species predicted to face range shift gaps under the no-migration scenario are predicted to do better under the full migration scenario since they retain at least some portion of their habitat areas as they move upslope (Appendix Table). Between the two growth forms, the grass growth form is predicted to have significantly ($P < 0.05$) higher habitat area than the legume growth form (Table 1). However, no significant ($P > 0.05$) differences were predicted to occur in habitat area loss among the eleven genera, between the grass and legume growth forms, between the annual and perennial life forms and between the clonal and non-clonal modes of propagation (Table 1).

4. Discussion

4.1. Current species distribution

The present study has demonstrated that a large number of the dominant grassland species are concentrated on mid-altitude areas

giving a characteristic hump-shaped distribution. Similar types of plant distributions have been reported by many authors along altitudinal gradients in tropical environments (Desalegn and Beierkuhnlein, 2010; Aynekulu et al., 2012; Namgail et al., 2012). The hump-shaped distribution of species could be because of wider altitudinal range (Fig. 2b) and proportionally more habitat area availability (Fig. 2c) in the mid-altitude which provides the species with combinations of climate, water and energy dynamics that have direct effects on plant physiological performance (Desalegn and Beierkuhnlein, 2010). Although the area available for species is larger, only few species are recorded at lower altitudes (Fig. 2a). This is because of high temperature and low annual rainfall conditions that have influenced growth, development and distribution of the species. On the other hand, the low number of species observed at higher altitudes could be due to cooler temperature conditions that limit physiological performance of species to adapt and survive in this environment (Namgail et al., 2012). Although the area available for species increased with altitudinal range, some species with a wide altitudinal range did not occupy wide areas and vice versa. This could be due to the shape of the mountain and slope of land over which species exist. In mountains, the area available for species generally decreases with altitude (Fig. 2c), and there is less area over a wider altitudinal range in the steeper part and conversely more area over a narrow altitudinal range in the gentle part of the mountain (Colwell et al., 2008; Kreyling et al., 2010).

In the present study, except among the genera and between growth forms, no differences were detected between life forms and modes of propagation in the current altitudinal range and area occupied. This shows that despite differences among legumes and grasses (in the current area), annual and perennial species as well as species propagated by clonal and non-clonal plant parts have similar altitudinal ranges and area occupation along the altitudinal gradient.

4.2. Projected species distribution under future climate

Human induced land use and land landscape fragmentation might have restricted the range of some dominant grassland species at

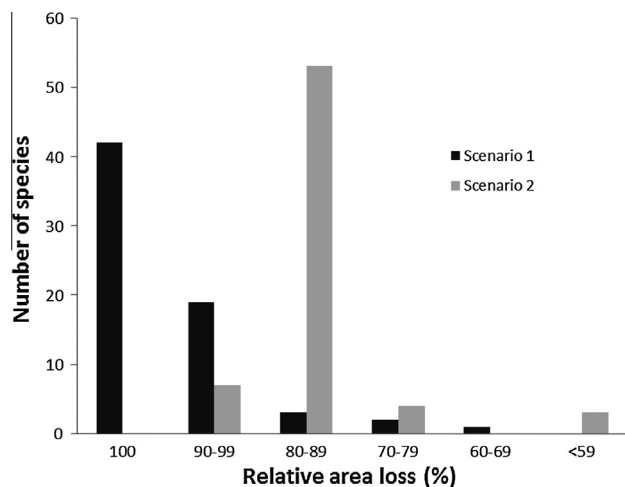


Fig. 3. Predicted percentage change in habitat area of species determined from Digital Elevation Model and GPS readings under no-migration (Scenario 1) and migration (Scenario 2) scenarios to predicted 4.2 °C increases in temperature by 2090.

low- to mid-altitude areas. As is evident from the weather station data described in Section 2.1, the temperature is higher in the low- to mid-altitude areas and species living in such areas might be living currently under their maximum tolerance to the rising temperature. A small increase over the current temperature level may thus force them to respond to the change. One such response already seen for other species under different environments is to move upslope towards their optimum or maximum level of temperature tolerance (Pauli et al., 1996) or face consequences of the warming temperature (Kreyling et al., 2010) given the case in Scenario 1, many of the species face range shift gaps which imply complete loss of habitat with a high degree of extinction.

The range shift gaps and habitat loss caused by rising temperature, however, did not differ among species belonging to different life forms (annual vs. perennial) and modes of propagation (clonal vs. non-clonal). This could be because of similarities in altitudinal range and habitat area occupied. The legume growth form, because of naturally narrow range of adaptation (Gebu, 2009), however, is predicted to be affected significantly more by range shift gaps, and habitat area loss than the grass growth form. Loss of legumes to climate-induced extinctions from the agro-ecosystems, however, could result in instability of the whole system as it leads to reduced or lack of nitrogen fixation, and incorporation into soils. As a result, growth of the non-nitrogen fixing species in the grassland community would be impaired and consequently may lead to loss of species from the system (Pausas and Austin, 2001). On the other hand, although the mechanisms are not yet clearly understood (Kreyling et al., 2010), occasional long-distance dispersal events have been found to occur among some plant species between geographically isolated Afro-alpine mountain ranges (Ehrich et al., 2007; Kreyling et al., 2010). This may help species to perpetuate even under conditions of fragmented habitat if it also holds true among the grasses and legume species under study.

It is also apparent that some species of grasses and legumes that are predicted to suffer from range shift gaps and habitat-loss induced extinctions under Scenario 1 are predicted to benefit from Scenario 2. The implication is that for narrow ranged and endangered species, modification of the current land use system through management intervention is of paramount importance (Opdam and Wascher, 2004; Brooker et al., 2011). The management option to be followed, however, would be better if implemented in such a way that habitats and dispersal corridors are interconnected. This is to accommodate species of different genera with different

growth, life forms and modes of propagation as they face similar problems of environmental and anthropogenic effects to migrate against warming climate from the model.

Thus fragmented plots of land would need to be connected especially for creeping-type grasses propagated by rhizomes and stolons. Assisted colonization could also be a feasible solution to dispersal-limited species of grasses and legumes (Brooker et al., 2011; Lunt et al., 2013). Since the study did not cover the full geographic range to the top of the highest summit (4036 masl) above the current limit, full geographic range of species found above the last altitudinal limit of the present study is not available to predict mountain top extinction risks. Intensive surveys may be required across the whole geographic range of the country to predict mountain top extinction risks. Further studies are also required using robust models that can accommodate multiple factors for better prediction of species response to future climate over larger area.

5. Conclusions

The results of the present study show that projected warming could significantly affect grassland herbaceous plant communities. Plant species differ in their response to the projected warming both under the no-migration and with-migration scenarios. Altitudinal ranges and habitat areas of the species are predicted to be significantly affected. All species face range contraction and habitat losses with range shift gaps among forty two species – mostly legumes, representing 17.9% of the species, recorded in the study, under a no-migration scenario. With the migration scenario however, 63% of the study species are predicted to benefit from retention of at least some portion of their habitat area. Between growth forms, legumes are predicted to lose significantly more range and habitat area than grasses under the no-migration scenario while no significant difference was predicted in habitat area loss between the two growth forms under the migration scenario and between the two life forms and modes of propagation. Hence it can be concluded that management options are required to help species migrate upslope to survive. These may include leaving end-to-end connected mosaic dispersal corridors along altitudinal gradients running from bottom lowlands to the top of the highest summit. Assisted colonization could also be a feasible solution to follow depending on species dispersal behavior and level of extinction risks predicted under the projected warming.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.biocon.2013.09.020>.

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